ANALYSIS OF RESIDENTIAL INDOOR POWER LINES AS A COMMUNICATION MEDIUM

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ABSTRACT

The interest in the study of power networks as a medium for information transmission is emerging nowadays. The subject of this paper is to analyse the network inside the consumer premises in order to attain a channel model of these lines, useful to simulate high bit-rate digital communications. A procedure to obtain frequency amplitude and phase characteristics, and impulse response, from the network parameters and topology, is proposed. Results are obtained for some real scenarios and compared with actual measurements. Disturbances that appear in this kind of environment are discussed.

1. INTRODUCTION

There is an increasing concern for using the power distribution lines for communication purposes, upon the economic advantage that this network is already installed everywhere. However this attention is not new. Since the first quarter of this century power delivery companies have been making use of the distribution lines for operation and maintenance. There are also available some analog communication applications based on indoors electric lines as baby-monitors, intercoms, and audio or video distribution equipment.

Nevertheless is digital communications what rule telecommunications activities today, and certain interesting applications arise in this area. One of them is the use of the low voltage network as access to wide area telecommunications networks (the so-called “last mile”), supporting services like Internet, cable television, ISDN or basic telephony. The latter is a good opportunity for companies after the recent fall of the telecommunications monopoly in Europe.

So far indoor applications have been mainly restricted to low data rate communications, like building and domestic automation systems (there are already modems available for this matter). In fact, there are regulations in Europe that limit the frequency range from 3 kHz to 148.5 kHz [1]. This constraint is extended to 500 kHz in America, Japan and other parts of the world.

The purpose of this investigation is to get some insight in the use of indoor power lines to transmit high data rates, which would permit to establish a Local Area Network (LAN) in every home or office without installing new wiring. Of course, an extended frequency band has to be released to allow this possibility, which seem to be feasible if technology demands it.

2. DESCRIPTION OF THE MEDIUM

Power lines were designed, obviously, to deliver electrical energy (by means of signals of low frequency and high voltage) and not to transmit communication signals (usually at higher frequencies and lower amplitudes). It makes the conditions in the channel quite adverse. Not much is known about electrical wiring as a communication channel. Few measurements at high frequencies have been performed [2], showing serious difficulties to describe the channel parameters, i.e. noise sources, amplitude and phase response, or input and output impedance. These properties depend on the particular residence characteristics under study: complicated and often unknown topology (with many branches), kind of wires involved, heterogeneous loads... Also exhibiting variations with frequency, location and distance, and time (as domestic appliances are switched on/off).

Recent noise measurements have been carried out [2][3], pointing to several important noise sources that can be classified into four categories: background noise (whose spectrum has a regular decay with frequency), impulse noise (due to single events like connection/disconnection of loads), noise synchronous to the power frequency (caused by devices switching periodically to the power system frequency, like motors), and finally narrowband noise (generated by radio interferences, switched power supplies, etc.).

In this kind of channels the transmission link is established connecting the transmitter and receiver equipment between the line and neutral conductors of the power grid. Medium size residences are normally supplied by two conductors: line (one of the three distribution phases), and neutral; and loads are placed between both. In contrast to industrial and commercial buildings, which are generally powered by the three phases, and big loads are connected with two of them.

3. CHANNEL MODELLING

This work is focused on dealing with indoor power networks for information transmission in a systematic way, despite the previously mentioned difficulties. In the light of preceding literature about the topic [2][4], it is reasonable to consider time variations of system parameters slow enough to assume time-invariance during a symbol interval, which justifies the estimation of the channel impulse response.

The proposed theoretical model is based on viewing power lines as a structure of transmission lines (an idea already used in other environments like digital subscriber line [5]), with multiple branched lines that may be loaded or unloaded. The frequency response (both amplitude and phase characteristics) is obtained then by recurrent multiplication of complex matrices corresponding to every transmission line section. In case the branched line is loaded (i.e. there is an electric appliance plugged in), a complex impedance models it, otherwise an open loop is considered.

Even though network input impedance value changes considerably, it is usually rather low (in the range of few ohms), what means mismatch coupling in the transmission part and hence additional losses. Therefor the simulations have to include this effect.

Data from manufacturers of typical cables used in power wiring have been adopted in order to find the secondary parameters (R, L, C, G) of two parallel wires, which will be the elementary transmission line. These wires are typically made of copper, with different sections (from 1.5 to 10mm^2), isolated with PVC.

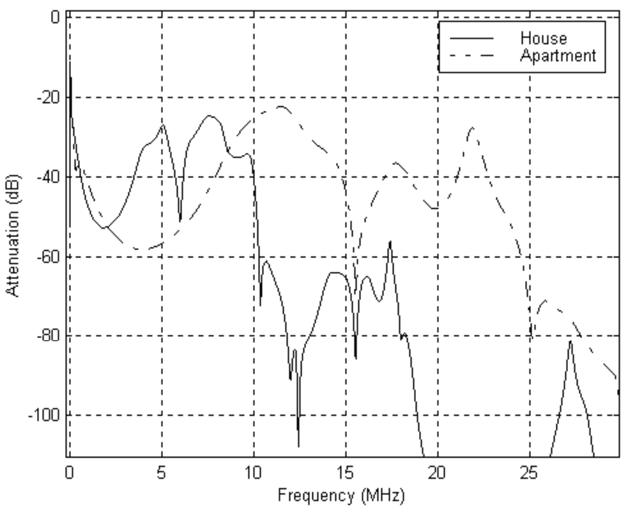

Figure 1. Channel attenuation versus frequency for two home power line networks simulated.

From actual electric layouts of several residences, approximate transmission line models have been carried out. In which some sets of loads have been contemplated, assuming impedance frequency averaged values (through the mains plug) obtained from measurements up to 30MHz (e.g. incandescent lamps impedance ranges approximately from 25 to 200Ω, a TV-set or a personal computer impedance can be between 5 and 600Ω, etc.).

The results obtained by model simulation for two scenarios are shown in Fig. 1, where curves represent the magnitude frequency responses (attenuation of the channel) of a link located inside a house, with a distance between transmitter and receiver of about 40m; and another inside an apartment, with a distance near 30m. Notches in certain frequencies are observed, as consequence of wave propagation phenomena that appear due to impedance mismatch and branched lines. These 'nulls' correspond, for instance, to frequencies at which un unloaded branch length equals a quarter of the wave-length in the line.

It is clear the channel attenuation strong dependency on topology and distance involved. Despite the chaotic appearance, the drafts reveal some narrow subbans with 'flat' response that could be combined for reliable transmission at high data rates. However there is a high attenuation level (observed even in short-distance links), caused by the multiple branches, which can be seen as many loads in parallel, and that reduces notably the power that reaches the receiver, and obliged to good detection techniques.

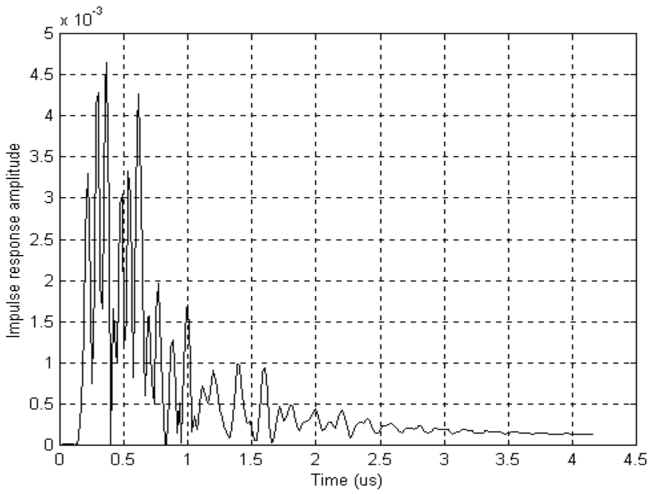

Figure 2. Impulse response of a two home power line channel simulated.

In Fig. 2 impulse responses for the house power line configuration is plotted. It is remarkable the different impulses, that appear like echoes, produced by the multiple reflections that signal experiments as it travels through the network. This is a multipath propagation effect typical in other communication channels as the radio ones. The delay of the first impulse changes depending on the transmission distance, and the nature of wires. The more branched and loaded the network is, the longer the impulse response.

4. MEASUREMENTS

It is clear that a coupling circuit will be needed to protect the equipment communication terminals against mains power signal. This coupling circuit basically consist in a high pass filter (with low cut-off frequency) and a transformer that provides galvanic isolation. Hence it has been necessary to take into consideration the coupling circuit load effects to attain the global response of the channel.

Measurements of noise power and channel transfer functions have been performed for different indoor power line channels under various conditions and loads, so that the simulation results could be verified.

Obviously, the measurement set-up changes depending on what it is going to be registered. When noise measurements are performed, only a spectrum analyser (or a digital oscilloscope and some data processing) plus the coupling circuit are needed. In Fig. 3 the averaged noise power density measured in a certain power-line channel of a laboratory is plotted.

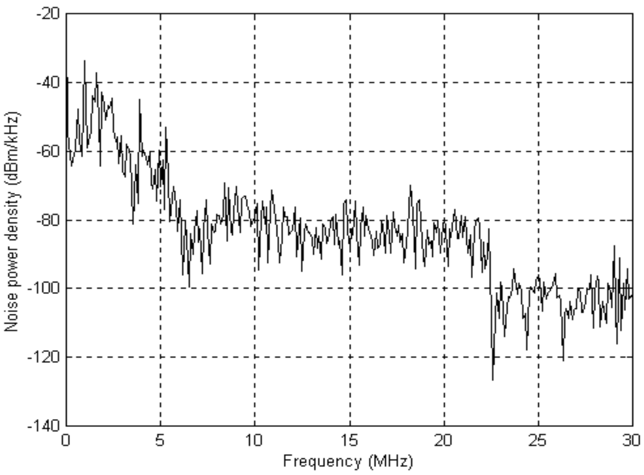

Figure 3. Noise measured in a laboratory power line.

It is noticeable its profile like descending steps as frequency increases, which could help to model it as the superposition of several sources of filtered white noise with different power densities and pass bands [6]. Some narrow band interferences have to be added in order to model the peaks that appear.

On the other hand, a network analyser plus two coupling circuits are used to obtain the transfer function of the channels. This has been done to study the performance of a power line channel in the laboratory, whose magnitude frequency response is shown in Fig.4, where the pass band characteristic of the channel is observed.

Three curves, corresponding to the same location of transmitter and receiver but with different appñiances plugged in the vicinity, are drafted, so that the effect of load changes can be appreciate.

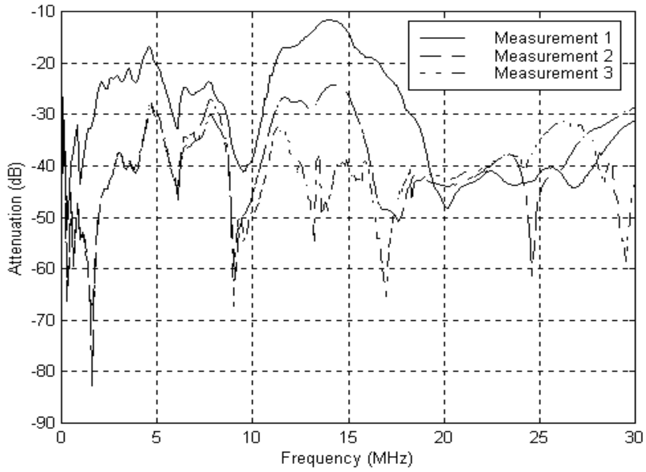

Figure 4. Channel attenuation of a power line channel measured in the laboratory with different loads.

No remarkable time variations were registered in each of the outcomes (contrary to the noise measurements), except at low frequencies (possibly due to the higher level of existing noise). But it is clear that significant variations arise when a load is plugged in/out.

In the first result no load was plugged near the measurement equipment terminals, in the second, some typical laboratory instrumentation and lamps were connected; and in the third, a device with a little motor was added. The distance in this example is not accurately known but it could be some tens of metres. As in the model results, there is a high attenuation level and notches at certain frequencies are observable, being all this emphasised with the connection of loads.

In order to assess the validity of the simulation model a comparison has been carried out in a short distance link in the laboratory (see Figs. 5 to 7). The transmitter was located closer than 10m to the receiver (although the path length in this configuration was not precisely known). They both were connected to the same distribution phase.

The structure of the network involved was roughly estimated form the inspection of the electrical wiring characteristics to prepare the simulation. Obviously the model results should not be expected to match the measurements exactly. In any case this is not completely necessary, because the model will be used to evaluate the channel capacity and the performance of different transmission techniques in a statistical way.

The attenuation curves (Fig. 5) bear resemblance especially in the region between 4 and 20MHz. At high frequencies the correspondence is more difficult because the transmission line model does not take into account the radiated propagation of the signals, but int the actual measurements this influence is virtually unavoidable.

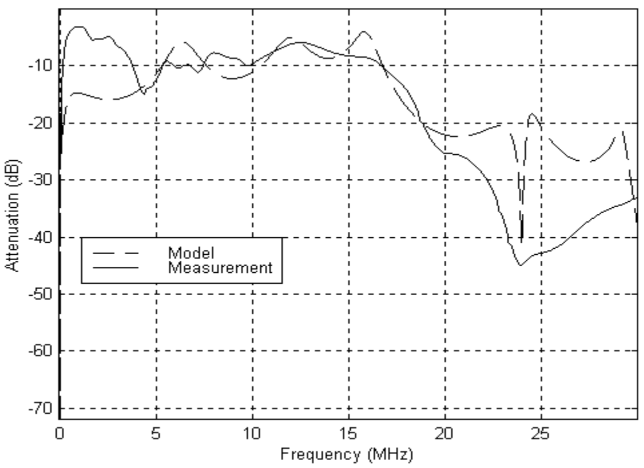

Figure 5. Comparison between channel attenuation of a power line channel measured in the laboratory and the result of an approximate simulation model.

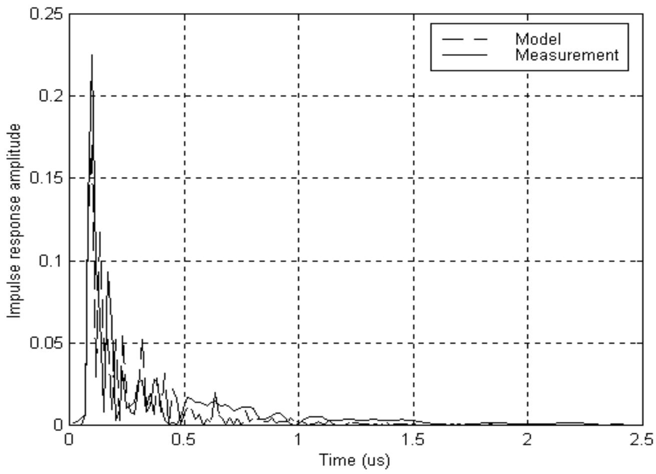

Figure 7. Comparison of the impulse responses.

The phase characteristics (Fig.6) exhibit a similar behaviour as well, showing non-linearity at frequencies where the channel attenuation presents nulls. The group delay (related to the phase derivative) is quite uniform except for these bands, which means no severe phase distortion.

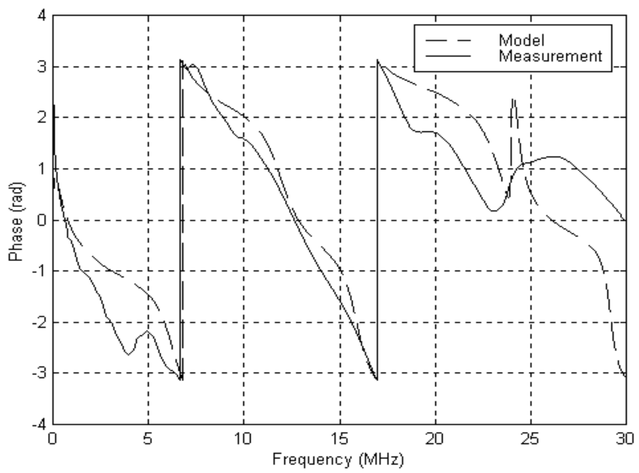

Figure 6. Comparison of the phase responses.

From the amplitude and phase functions in the frequency domain, impulse responses of the channels have been determined (Fig.7). They have shorter duration than the previous one, in Fig.2, because the network is less complicated in this case. The arrival time of the first impulse is also shorter as consequence of the path length reduction. The measurement and model result can only be distinguished in the secondary impulses caused by reflections in the lines.

5. CONCLUSIONS

The purpose of this work is to present a procedure to achieve a channel model for power-line communications inside residential buildings. From the network characteristics and topology a software model has been made, and appropriate measurements are being carried out to validate it. This method will be very helpful to estimate, through simulation, the information capacity of this kind of channels, also to evaluate the performance of different digital modulation schemes.

The channel model simulated has to be improved by considering more accurate load models, and modelling noise sources. Once it has been sufficiently assessed, it will be possible to study the statistical behaviour of these channels by varying the physical parameters in a clever way.

So far, results of simulated models from real scenarios and measurements indicate that transmission at high data rates could be feasible. Although it is expected that the communication system must face up to high levels of signal attenuation and several noise sources, and these conditions are going to be time variant. Moreover, due to the complicated topology of the network (with multiple branches), certain frequency notches arise, which obliged the system to avoid these narrow bands. It suggests that robust transmission techniques will be needed, like multicarrier modulation (OFDM, orthogonal frequency division multiplexing) or spread spectrum. This could be subject for future investigations.

6. REFERENCES

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